Sensitivity study of Refracting Materials in the feasibility of EO (Earth Observation) missions at VLEO (Very Low Earth Orbit)

Bachelor's Degree Thesis

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Abstract

This thesis develop a feasibility study of refracting materials for EO (Earth's Observation) missions in VLEO (Very Low Earth Orbit).

With the information collected to establish a base case, the DISCOVEX tool will be used to extrapolate this information to missions with different specifications and, with this, obtain the economic factors that define the project.
Relating these results, are reflected the investment factors that can be associated, maintaining economic stability, with the improvement of a Cubesat satellite system, including the materials that compose it.

It explains how to get the answer to the question:
How much can be invested, at most, in improving satellite materials to have it a number of years working in VLEO being feasible?

ANNEX VI – DECLARACIÓ D'HONOR

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Chapter 1

Aim of the project

The aim of this project is to realize a feasibility study of EO (Earth Observation) missions at VLEO (Very Low Earth Orbit), where the atmosphere is much more aggressive. The objective is to characterize the economic influence of the material in this type of missions, taking into account the other systems present on the satellite.

It will try to evaluate the impact of the materials in economic terms and life time, in order to find key factors that indicate when and in what conditions it is advisable to make improvements to incrase the usefull life of this type of orbits.
From the real base case, economic and technical data will be obtained that will be extrapolated to different missions whose most important variation is the lifetime and economic values related to the captured image that would provide the benefits.
The difference between some cost and investment factors, will gives an estimate of the fraction of money that could be used to improve each satellite, for example to materials.

The final objective of this thesis will be to estimate what fraction of the budget could be used to improve materials in CubeSats satellites to maintain these types of missions viable.

Chapter 2

Scope & Requirements

2.1 Scope of the project

The scope of the project will be affected by the absence of economic data in relation with developing materials.
This is the reason why the process to follow will require an indirect study that provide *extra* economic values that will be associated not only with the possible materials to be improved, but also with the whole set of possible improvements to be added to the satellite, for a feasible mission
This includes the following points:

- Study of the PLANET mission, which will base the initial case, providing technical and economic data of the different aspects of cost and investment; launch, manufacturing, payload.
- Analysis of the DISCOVEX tool available, with the functionalities that will be used.
- Addition of the new functions in DISCOVEX for the individual economic analysis of an individual satellite (Cubesat) and explanation of them.
- Feasibility study of the different case with results.
- Environmental impact that this study can have.

2.2 Requirements

To meet the objectives, certain requirements are necessary, in order not to exceed the framework in which the analysis is performed.

- The research will be about VLEO orbits.
- The only satellite considered for the studies is CubeSat.
- The base mission to study will be PLANET mission.
- The tool used to simulate the values of the missions generated from the base case will be Microsoft Excel.
- The payload will be Earth's surface images and the payback will be the value of this in the market. ($\$/Km^2$)
- The type of material is not taken into account to estimate economic values, but a previous analysis of the influence that each of them can have will be done.
- Estimates refer to all other possible aspects to investment; ABEP, systems, payload, ground stations...

Chapter 3

Background & Justification

For a long time ago, the need for satellites became indispensable. There are thousands of devices *flying* around the planet. Most of them do so at altitudes, between 450-900km, called *low Earth orbits*, in the following, LEO.

Nevertheless, for more than a decade, different universities and research centers have been trying to develop satellites to locate in a lower orbit (300-450 km). It is *very low earth orbit*, from now VLEO.

While in LEO (450-900 km) the mission lifetime varies between 20 and 75 years, in VLEO it does not exceed 3 years [1]. This is due to the disturbances that generate aerodynamic forces and degradation of materials.
However, the amount of benefits of this type of orbit should not be forgotten:

- Increased Radiometric Performance
- Increased Payload Mass (from Launcher)
- Increased Geospatial Position Accuracy
- Increase of the Effective Surveillance Footprint Size
- Lower Risk of Collision with Space Debris

among others [1].

3.1 Aerodynamic force & Atomic oxigen degradation

The degradation by **atomic oxygen** of the materials presents an essential problem to solve.
At VLEO altitudes, this element is very much present and it's a highly reactive species, which seriously deteriorates the surface of satellites.

Being one of the main atmospheric constituents in the thermosphere 3.1[2], the atomic oxygen can cause concerns on which will be its impact on sensitive surfaces. The development of materials resistant to this type of degradation will be vital in order to make use of the VLEO.

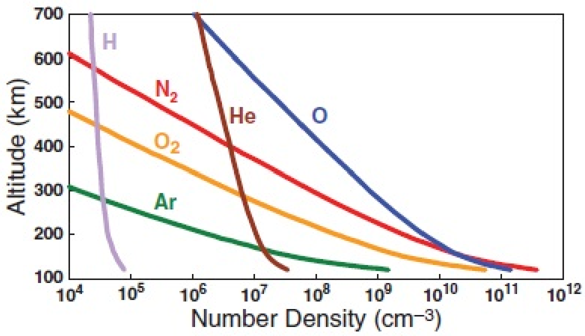

Figure 3.1: Atmospheric composition in the low Earth orbit.

The chemical reaction of ATOX with a surface may cause the formation of volatile oxides from polymers, carbon, and osmium; or oxides which do not adhere very well to the surface and tend to spall, as in case of silver. Volatile and spalling oxides contribute to the erosion of the surface.[3].

On the other hand, the orbits in denser areas of the atmosphere implies a greater influence of **aerodynamic forces**, mainly drag force. This condition requires a specific design aimed to reduce drag, together with a propulsive system that compensates for the fall that these forces generate in the satellite's orbital trajectory. On many occasions, these aerodynamic forces can be used as control of altitude of the orbit or fall to the ground.

3.2 CubeSatellites

Within the category of nanosatellites (1-10kg), those evaluated in this project are the CubeSats, which, as the name implies, have a cube shape.
It was developed by the California Polytechnic Institute as a low-cost model to send satellites with a low budget, focused on the university environment.[4]

The truth is that these satellites have several advantages beyond their geometric simplicity. They can house many types of systems useful for terrestrial observation.
They are usually sent as secondary payload in the missions and are very standardized; dimensions, prices, market opportunities. [5]

Taking as reference a CubeSat unit, (1U), major formations are commercialized (2U, 3U, 6U), depending on the need, which makes its manufacturing much more comfortable. [6]

In summary, many opportunities are being offered to solve the different problems to carry out these missions, introducing new geometries and propulsion systems. These new routes, still in development, require the use of new materials, more resistant to erosion and more efficient in increasing the satellite's useful life.

However, it is possible that the development of these new materials will involve an investment that is too high in the project, leaving a zero or negative profit margin. Therefore, it is necessary a specific analysis of the expense, not only in materials, but in all systems that should consider to have a satellite, in VLEO, with a longer lifetime, being profitable.

This project will attempt to answer the question; How much should the material cost to make it profitable to place the satellite in this type of orbit for a concrete time?, which represents an important step for the implementation of VLEO.

Chapter 4

State of the art

The use of VLEO presents a series of challenges in contrast to the benefits that can be obtained from it. There are many examples of missions in LEO, which demonstrate the usefulness and benefit of using low orbits, while, regarding VLEO missions, most are concepts still in experimental phase in laboratories. In other cases, such as Planet's, this orbits are managed and used like a business.

Many of the satellites used in these missions were directly or indirectly affected by the effects of orbiting at very low altitudes, and although some met the mission's objective. They are examples of the complexity but, the possibility too, of making these projects viable.

4.1 LEO & VLEO missions

Both the benefits and the challenges of using this type of low orbit are clear. The LEO missions made in recent decades are not few, as are the projects under development to take advantage of the VLEO. Some of them are cited below.

GOCE

The Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) was the first of ESA's Living Planet Programme satellites intended to map in unprecedented detail the Earth's gravity field.
Located at 255 km of altitude, GOCE was operational between March 2009 and November 2013, allowing a very detailed analysis of the earth's gravitational field, using an ion propulsion system to minimize the errors due to vibration of conventional propulsion systems.[7]

GRACE & GRACE-FO

The Gravity Recovery and Climate Experiment and The Gravity Recovery and Climate Experiment Follow On are two satellites used for the same mission in LEO (500 km), whose objective was to analyze the anomalies of the Earth's gravitational field.[8]

EarthCare

It is an European/Japanese satellite, the sixth of ESA's Living Planet Program at 390km of altitude.
The main objective of the mission is the observation and characterization of clouds and aerosols as well as measuring the reflected solar radiation and the infrared radiation emitted from Earth's surface and atmosphere. The satellite will make measurements useful for better understanding the Earth's thermal and solar radiation balance.
The project began in 2009, with the goal of make the last launch in 2021. The project budget is set at 590 M€, with the design and manufacture of the satellite responsible for 260 M€ of them.[9]

4.2 VLEO concepts

Now, many institutions such as the Cranfield University have studied in depth the concepts necessary to deal with the problems of this type of orbits, as well as contrast them with the benefits it brings. Some of these projects are cited below [1].

THOR

The Thermospheric Orbital Reconnaissance (THOR) mission study aimed to demonstrate the commercial viability of a VLEO very high resolution ground imaging spacecraft. The selected orbit was 227 km away and faced challenges such as the management of the data obtained or the protection of the payload against atomic oxygen. With this, the estimated mission total cost is estimated at 1165.5 M€ including a 22% margin.
The project served to show a possible spacecraft configuration if the VLEOs begin to explode[1]. However, one of the premises to be profitable in the use of these

orbits is that their implementation is not more expensive than those currently existing.

DMC-HD

DMC-HD aimed to be a low-cost high-resolution Earth Observation (EO) mission with a near-term implementation, adapting a commercial platform to fly in VLEO. The project studied at different altitudes which would be the modifications required and which would be the benefits[1].

The resulting designs have different operating altitudes (hence different resolutions) and different operating configurations. The design that was estimated to be most commercially profitable was the one that was flying lower (315 km).
This design was capable of providing panchromatic imagery with ground sampling distance of 47 cm, a swath width of 11 km, 3 m geospatial position accuracy and with the capacity to collect more than 25,000 km2/day.
The total cost of a constellation of two spacecraft (including development, launch and insurance) ranges from $95 million to $112 million.[10]

VLEO SAR

Synthetic Aperture Radar (SAR) missions can also benefit from lowering their operational altitude [11]. SAR platforms seem well suited to operate in VLEO as they use rectangular and elongated antennas that need to be oriented in the along-track direction. This results in some SAR mission designs already adopting slender configurations (such as TerraSAR-X, Tandem-X, Paz and NovaSAR).
The benefits of lowering the operational altitude of SAR instrument are mainly a reduction of the antenna area or a reduction of its power. Having a smaller antenna and a lower power requirement can led to smaller, lighter and hence lower cost platforms.[1]

All this gives an overview of the aconomic values that this market moves, as well as the boom that can be seen in it.
However, this thesis will be based on the mission carried out by PLanets Labs, which will be discussed in more depth in the next chapter.

4.3 Atomic oxygen effect in aerospace materials

The influence of this effect depends on many factors; ATOX fluence and impact energy, material temperature, thermal stresses, Synergistic solar radiation, impact angle...

An example of this effect is very appreciable in the International Space Station (ISS)[12], which is in an orbit about 400 km above Earth's surface.
The atomic oxygen has been responsible for the deterioration of many surfaces of the ISS structure. The impulse and maintenance needs together with the rapid degradation through the orbital space has even generated the doubt of whether it is really profitable to keep the station in orbit.

Obviously, the type of material will present a different response to this phenomenon.

4.3.1 Atomic oxygen on metals

Experiments on metals were carried out during many flights, on LDEF (Long Duration Exposure Facility), Eureca (European Retrievable Carrier) and on ground. The majority of the experiments were conducted on silver, while at the time of the Hubble Space Telescope development silver was used as solarcell interconnectors.[3]

The oxidation of silver in atomic oxygen is essentially linear-parabolic as postulated by De Rooij and experimentally confirmed by Chambers. [13].
Following these postulates, it was calculated that in a typical ISS orbit, the loss of silver due to the effect of atomic oxygen was 11.5mm per year, increasing to 300 when the flaking is assumed.

Definitely, in the low Earth orbital environment, one should not use materials which suffer from atomic oxygen corrosion on external surfaces nor on surfaces which can be reached by atomic oxygen neither should one protect materials such as silver by materials with low erosion or corrosion yields.

Other metals investigated are Cu, Au, Al, stainless steel, Ta, Al alloys and Mo. These materials were exposed with and without coatings, such as silicones. Cu was exposed during different missions and showed a severe darkening (dark red) of the surface, changing the optical properties significantly. The copper oxide was adherent to the surface. Other groups investigated Os, Pt, Ni, Fe-alloys and carbon.

Neither of them have good and not very expensive characteristics against this phenomenon.

4.3.2 Atomic oxygen on no-metals

It is well documented through orbital and ground measurements that most hydrocarbon polymers and active metals are highly reactive towards the orbital atomic oxygen.
Materials containing silicones, fluorides, oxides and noble metals are believed to be moderately inert for short exposures to atomic oxygen. However, samples recovered from LDEF indicate that many materials are severely degraded on long-term exposure to atomic oxygen.

The tests conducted by T. Miller[14] indicate that environments which produce synergistic effects with regard to the magnitude of erosion by atomic oxygen exposure are not the same for each polymer. Each polymer appears to be sensitive to a different component of the environment. Predicting the atomic oxygen durability of a material in the space environment can be a very complex task worst by the fact that each material may be sensitive to a different synergistic component in the environment.

4.3.3 Atomic oxygen on graphene

The development of graphene has been a great advance for the scientific community, presenting as many applications as there are sciences.
In the space field, the expectations have increased, allowing the development of compounds with very varied characteristics and suitable for each purpose. The experiments with graphene before the degradation by atomic oxygenation are several, showing very good results.

The Beijing Key Laboratory for Powder Technology Researchand Developmen realized an study where epoxy resin/graphene nanocomposites were prepared by the solution mixing method, to expose it to this effect. The results of ATOX erosion resistance of epoxy resin/graphene nano-composites is improved.
A 46% decrease in mass loss anda 47% decrease in erosion yield were achieved by the addition of only 0.5 wt% of graphene.[15]

There are many institutions that have shown interest in this material, from NASA or ESA to more current institutions such as SpaceX, as well as smaller project groups.

The use of graphene can bring the possibility of having greater resistance to degradation by atomic oxygen and, consequently, that orbital objects have a longer life time. At the moment, the price of this materials is quite difficult to specify.

4.4 Resume

Advances in materials and design allow keeping the expectation very high, among other, on the exploitation of VLEO.

Combinations of graphene together with suitable coating designs and refractive components in other materials will significantly increase the useful life of the affected materials and, consequently, the satellite's lifetime.

The value of the materials and the rest of the components needed to maximize the efficiency of the entire system will be essential, so the cost of these must be estimated and evaluated, and also the maximum possible investment that it can be done in this regard to make the project feasible.

Subsequently, the possible income that these missions could contribute will be evaluated, to contrast them with the expenditure they require.
To do this, in the next chapter will be analyzed a PlanetLab's mission, to obtain the necessary information and data and use it like a base case to develop this thesis.

Chapter 5

PlanetLabs case study

Planet Labs was founded in 2011 by three ex-NASA engineers to disrupt the traditional aerospace industry by using modern consumer electronics manufacturing techniques to build a large constellation of nanosatellites.
It is the only fully integrated company that designs, builds, and actively operates satellites while also delivering data to customers via an internally developed web-based platform. Planet Labs employs an "always on" line-scanning image capturing method as opposed to the traditional tasking model used by most satellite companies today.[16][4]

For this and the characteristics of their missions they are presented as an ideal base case to develop this thesis

5.1 PlanetLabs satellite- The *Dove* spacecraft

The Planet Labs Dove satellite design is based on the "3U" cubesat. Planet Labs refers to a group of Doves deployed simultaneously into a single orbit as a flock.

These flocks, located in the different required orbits generate the constellation, through which it is intended to capture the Earth's enter surface every day.

Planet Labs captures imagery using a telescope and camera combination which has been optimized for this form factor. The imaging system aboard each spacecraft captures red, blue and green (RGB) imagery.
Planet Labs is currently developing Near Infrared (NIR) imaging capabilities. Something that has already been studied in other occasions through the DISCOVERER project [17].

Planet Labs has flown three generations of optical instruments: Planet Scope 0 (PS0), Planet Scope 1 (PS1), and Planet Scope 2 (PS2). Images have different attributes depending on satellite altitude and instrument type.

Today PlanetLabs has more than 140 satellites orbiting, allowing you to have an almost complete view of the Earth's surface.
It also manages medium and high resolution images, which translates into 3 types of satellites with three types of payloads.

	PLANETSCOPE	**RAPIDEYE**	**SKYSAT**
Bands	4 (RGB, NIR)	5 (RGB, red edge, NIR)	5 (RGB, NIR, pan)
Product	Color enhanced Visual Analytic	Color enhanced Visual Analytic	Visual Panchromatic Pansharpened multispectral Analytic
Pixel resampled	3 m	5 m	Visual, panchromatic, pansharpened multispectral: 0.8m Analytic: 1m
Radiometric resolution	Visual: 8 bit Analytic: 16 bit	Visual: 8 bit Analytic: 16 bit	Visual: 8 bit Analytic, panchromatic, and pansharpened multispectral: 16 bit

Table 5.1: Main characteristics of the three Planet Labs satellites.

This information has been extracted from the company's website [18]and is available to anyone.

5.2 PlanetLabs mission

Planet Labs does not employ the traditional "tasking model" for space-based imagery collection. In the traditional model, imagery collections are prioritized and planned based on "targeted" collects with little or no imaging of non-prioritized areas. Planet Labs' satellites are designed to operate in concert to continuously collect imagery of the sunlit portion of the Earth's surface. At full constellation, Planet Labs' monitoring capability is expected to yield approximately one complete global image dataset every day.

The initials launched to generate the constellation are listed in the following table[19], which refers to the launches carried out to date 2015. From then on PlanetsLabs begins to collect and manage Earth's images.

Flock Name	**Launch date**	**Orbit**	**Quantity Launched**	**Quantity Operational As of July 2015**
Flock 1a	1/9/2014	ISS	28	0
Flock 1c	6/19/2014	SSO (620km)	11	8
Flock 1b	7/13/2014	ISS	28	10
Flock 1d	10/24/2014	ISS	0 (Launch Failure)	0
Flock 1d'	1/10/2015	ISS	2	1

Table 5.2: Planet Labs Inventory of all Launched Satellite Flocks.(Until 2015)

As has been said, today the constellation consists of more than 140 satellites and PlanetLabs has laid its foundations in the Earth observation market[20].
A summary of the releases until today and their characteristics are shown in the following table.

Operator	Planet
Launch date	12 Satellites 22 June 2016, 88 Satellites 15 February 2017, 48 Satellites 14 July 2017, 4 satellites on 31 October 2017, 4 satellites on 12 January 2018, 16 satellites on 29 November 2018, 3 satellites on 3 December 2018, 12 satellites on 27 December 2018, 20 satellites on 1 April 2019
Mission Status	Operating
Orbit Type	Sun-syncronous
Orbit altitude	475 km ($\sim$ 98º inclination)
Number of satellites	120+
GSD	3.7
Image capture capability	265 million km^2/day

Table 5.3: Mission details PlanetScope

From here, this constellation will be taken as a reference, whose experience in launches, image taking and management will serve to the starting line for this project.
From this, the aspects related to the lifetime will be varied, in order to obtain the different economic variations that will indicate an estimate of the possible investment destined to improvements of space vehicles, as well as serve as a comparison with the current PLanet mission.

To carry out this *simulation*, very specific economic information will be needed on each of the factors that influence this type of missions, as well as a platform that can relate them.

This work was carried out, a few years ago, by a partner of the Discoverer project, Antonio Cabeza Doña, which gave rise to the DISCOVEX tool, whose characteristics and functions are explained in the next chapter of this thesis, and more in depth, in his[21].

Chapter 6

DISCOVEX, a CubeSat cost-model tool

In his thesis, Cabeza collects enough information to be able to generate a consistent database on which to work. The resulting tool, DISCOVEX, allows you to perform a financial analysis for VLEO missions, with the CubeSat as a reference satellite.
The specific description of the tool capabilities and its theoretical background and assumptions are described within the Master's thesis report [21].

The Excel file that forms this tool consists of several sheets, some of which serve as a database of the different aspects that make up the mission; (CAPEX and OPEX), and others whose values depend on the first ones (Cubesat budget, propulsion budget, launch service ...).

At the end, all this leads to a sheet that represents the financial model of the mission, from which two excel windows have been developed in this work; one for the feasibility analysis of the mission for more years in the future and another for the sensitive analysis of a single CubeSat.

The values that appear in the images of this chapter do not correspond to stable or analysable values, being only to have a visual representation of the highlights of the tool.

6.1 Financial model tab

In his work, Cabeza developed a table where all the values associated with the financial model are collected, obtaining estimates at view years.

6.1.1 Inputs

Taking into account all the values, *a priori*, constants that assume the prices of the systems, launch and those included in the operational aspects (OPEX), the specific parameters that characterize the mission must be defined 6.1, like are altitude, number of satellites or lifetime.

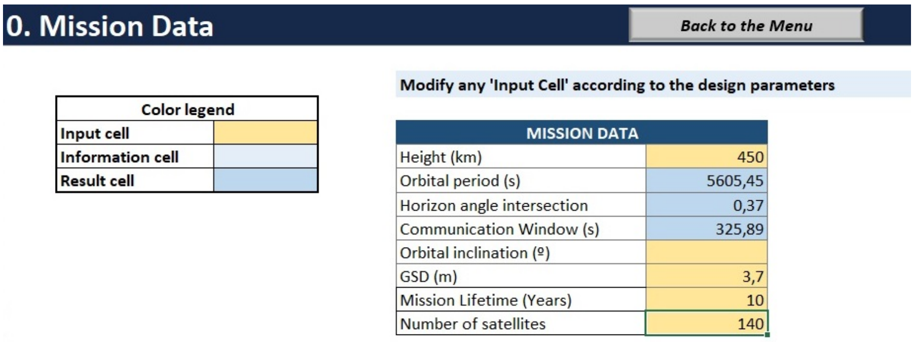

Figure 6.1: Mission data tab from DISCOVEX.

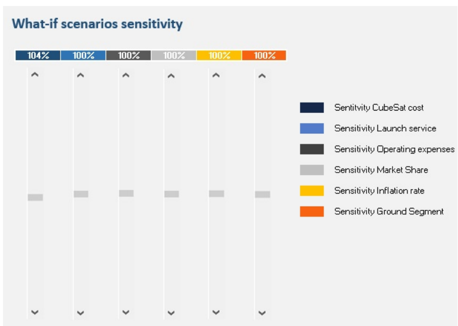

Figure 6.2: Sensitivity factors. DISCOVEX.

Once the economic factors such as the inflation rate or the percentage of useful and sold images have been introduced, the tool generates all the information resulting from the financial model.
In addition, the entire model depends on a sensitivity factor 6.2 as a percentage, allowing the results to vary according to an estimate in more or less optimistic cases

6.1.2 Outputs

Once the mission parameters have been defined, the financial model of DISCOVEX presents the results of applying such characteristics.
This results in cost and benefit ratios 6.3, as well as key factors such as the NPV, payback of IRR 6.4.

Financial model — Back to the Menu

	Forecast							
FINANCIAL MODEL	2018	2019	2020	2021	2022	2023	2024	2025
Inflation rate	2018	2019	2020	2021	2022	2023	2024	2025
Annual inflation rate for salaries	1,90%	1,90%	1,90%	1,90%	1,90%	1,90%	1,90%	1,90%
Annual inflation rate for salaries	1,02	1,04	1,06	1,08	1,10	1,12	1,14	1,16
Annual inflation rate for operating expenses	1,90%	1,90%	1,90%	1,90%	1,90%	1,90%	1,90%	1,90%
Annual inflation rate for operating expenses	1,02	1,04	1,06	1,08	1,10	1,12	1,14	1,16
Revenues								
Revenue of imagery (Worldwide)	2018	2019	2020	2021	2022	2023	2024	2025
Revenue of imagery								
Very high resolution	1.155.820.257	1.202.053.068	1.250.135.190	1.300.140.598	1.352.146.222	1.406.232.071	1.462.481.353	1.520.980.608
High-medium resolution	673.895.104	768.240.418	875.794.077	998.405.248	1.138.181.982	1.297.527.460	1.479.181.304	1.686.266.687
Annual growing rate								
Annual Growing Rate	2018	2019	2020	2021	2022	2023	2024	2025
Very high resolution	4%	4%	4%	4%	4%	4%	4%	4%
High-medium resolution	14%	14%	14%	14%	14%	14%	14%	14%
Business Market Share								
Business Market Share	2018	2019	2020	2021	2022	2023	2024	2025
Very high resolution	0%	0%	0%	0%	0%	0%	0%	0%
High-medium resolution	8%	8%	8%	8%	9%	9%	9%	9%

Figure 6.3: Financial model results example. DISCOVEX.(1)

Financial model — Back to the Menu

	Forecast							
FINANCIAL MODEL	2018	2019	2020	2021	2022	2023	2024	2025
EBITDA	2018	2019	2020	2021	2022	2023	2024	2025
	49.354.582	**56.190.615**	**63.761.109**	**72.141.986**	**81.416.966**	**91.678.359**	**103.027.951**	**115.577.975**
Financial expenses								
Financial expenses	2018	2019	2020	2021	2022	2023	2024	2025
Fundings (Venture capital)								
Funds yearly return								
Funds charge								
Cadency years								
Funds return	28.560.000	28.560.000	28.560.000	28.560.000	-	-	-	-
Cumulated investment balance	85.680.000,00	57.120.000,00	28.560.000,00	-	-	-	-	-
Performance	2018	2019	2020	2021	2022	2023	2024	2025
Capital investment	-	-	-	-	-	3.737.722	57.000.259	56.065.829
Annual balance	**20.794.582**	**27.630.615**	**35.201.109**	**43.581.986**	**81.416.966**	**87.940.637**	**46.027.692**	**59.512.147**
Cumulated annual balance	**- 153.750.425**	**- 126.119.810**	**- 90.918.701**	**- 47.336.714**	**34.080.252**	**122.020.888**	**168.048.580**	**227.560.727**
Flag Payback	0	0	0	0	1	0	0	0

Performance results
Pay Back
IRR
NPV
Discount rate

Figure 6.4: Financial model results example. DISCOVEX.(2)

With this, it's possible to obtain general information on the viability of these types of missions, allowing you to have a general idea of the factors that most affect you.

As mentioned before, to see a deeper analysis of this tool, its creation and its usefulness, we recommend reading the master thesis of Antonio Cabeza Doña [21].

6.2 Feasibility study tab

Although through the financial model is possible to get an overview of the values in which the budgets related to the mission moves, it was not prepared to assess all the different variations of it, in a clear and joint way.

DISCOVEX presents a good collection of data and relation of this well specified, but this thesis has worked to couple the results received, for different variations of the mission, in a clear, consistent and analyzable way, in order to facilitate a subsequent evaluation.

The feasibility study tab allows to relate the results obtained through the financial model and compare them over the years and the lifetime of the satellites.

6.2.1 Inputs

In order to evaluate the results in the most possible specific and real way, there are now a series of values that can be modified individually, shown in figure 6.5. In addition to the information provided by mission data tab, other more specific and related to its economy are now pointed.

Input data	First year
$/km^2	
% Useful images	
% ISS	
% Secondary	100,00%
% Sold photos	
Inflation rate	

Figure 6.5: Feasibility tab inputs. DISCOVEX.

- **% ISS and secondary launches** represents an important aspect to consider, since they differ greatly in cost but also in terms of advantages. In this section is possible to change and adjust as desired.

- **% Useful images** will have also greatly influence the economic evolution of the mission, so it can also be varied at ease.

- **% Sold images** will be a value to estimate, because is difficult to find real information about it. That is why it should be able to vary easily.

- The price **$/km2** is a very important factor to analyze the results, since the benefit of the mission directly depends on it, and the consequent possible investment.
  There are several companies dedicated to the commerce of this type of images, so is possible to find information about the sale price of them.[22]

- Finally, it is possible to vary the **inflation ratio**, to adjust it to the growth in value that image generated will have, over the years

Other factors such as the kilometers of image obtained per day have also been updated and taken into account, and can easily be varied if necessary. An important component of the tool is the learning curve used, which adjusts the calculations more.

With all this and the information already stored in DISCOVEX, is got different outputs discussed below.

6.2.2 Outputs

When all the information is added, the feasibility tab can present the evolution of costs and benefits over the years.

The interesting thing is that, by pressing the result data button, DISCOVEX will relate all values, through the financial model and enter them into a table such as the following:

YEAR	2013	2014	2015	2016
SATELLITES	2	37	71	89
#LAUNCHED SATS	4	61	60	32
ISS	-	-	-	-
Secondary	-	-	-	-
KM2/DAY	693.500.000,00	11.269.375.000,00	21.671.875.000,00	27.219.875.000,00
$/KM2	-	-	-	-
% USEFUL	-	-	-	-
% SOLD	-	-	-	-
TOTAL REVENUES	-	-	-	-
COSTS	6.956.212,74	30.403.500,82	42.006.109,31	36.183.216,18

Figure 6.6: Feasibility tab outputs (1). DISCOVEX.

The process will be carried out for different life times, grouping them all in another table 6.7.

	Year	2013	2014	2015	2016
1	Revenues				
	Costs				
2	Revenues				
	Costs				
3	Revenues				
	Costs				

Figure 6.7: Feasibility tab outputs (2). DISCOVEX.

It shows the variation of the different key elements introduced, in the inputs section, over the years. From a given initial value, DISCOVEX will vary depending on the need of each mission and the economic ratios and learning curve inside it.

In the two end lines the total costs and income generated throughout each year are obtained, up to 2025 and for 10 different lifetimes.
With this, DISCOVEX could presents a table where the accumulated balance of the mission arrived at 2020 and 2025 is represented, which allows a more concise representation of the results depending on the lifetime.

Accumulated balance	Year	Lifetime
	2025	1
	2025	2
	2025	3
	2025	4
	2025	5
	2025	6
	2025	7
	2025	8
	2025	9
	2025	10

Figure 6.8: Feasibility tab outputs (3). DISCOVEX.

Thus, it is easier to graph these values and observe the differences between each type of mission, as well as obtain specific values to relate such as the NPV, the IRR or the Payback for the different lifetimes.

	1	2	3
NPV			
PB			
IRR			

Figure 6.9: Feasibility tab outputs (4). DISCOVEX.

The graphs that represent the values of these output cells are shown and explained in the results chapter.

6.3 One CubeSat feasibility study tab

It is true that the fensibility tab allows to clearly represent the total costs and revenues that a large-scale mission would have, giving an idea of the benefits that it would have available.
But the objective of this thesis is to reach a value that can be associated with an investment in material improvements, something that did not allow analyzing a global mission with a large constellation.

That is why a new section has been created in DISCOVEX, that analyzes all this economic evolution over time and different lifetime for a single CubeSat.
What is the same, it has been assumed that the constellation that must be kept orbiting is composed of a single Cubesat.

This function tries to reduce the cost and revenue values individually for one Cubesat, which allows obtaining the economic balance it would offer.
With this balance, and taking as a base case a lifetime of 1 year, is possible to see the amount of money available to improve each satellite, including the material.

6.3.1 Inputs

Here the values to be introduced, in addition to the mentioned for *feasibility study tab*, are several, in order to adjust more to reality and allow to give current characteristics when DISCOVEX is required to use.6.10

INPUTS	
# SATELLITES	
KM2/DAY (1sat)	
$/KM2	
%USEFUL	
DEGRADATION RATE	
%SOLD	
Inflation	
REVENUES/DAY	
Lifetime reference	
Discount rate	

Figure 6.10: One Cubesat Feasibility study tab inputs. DISCOVEX.

- **Satellites**. Although the objective is to analyze a single cubesat, with this cell it is possible to carry out the whole process for the number of satellites required. This allows obtaining results according to the user's needs, as it may be the case that economic values nedeed be projects that include a small and specific number of satellites. DISCOVEX now, can offer it.
- **KM2/Day**. This data is also used in the other and is based on the information obtained from the Planet website [20], contrasting it with related articles [23].
  Based on the amount of kilometers that the Planet's mission captures, extract the scaled value to a single satellite.
- **Degradation rate**. This cell represents the degradation that each satellite has over time, because it is logical that each year the number of useful images that it sends decreases. It is a value to estimate under the information of previous experiences. Actually it is an input present in the *feasibility study tab*.
- **Inflation rate**. It is a percentage of annual increase in the sale price of the image, also influential in the process followed by the financial model. If the company grows by keeping the satellites in orbit, it is logical that their sales price increases in percentage, as has happened in the base case of Planets.
- **Lifetime reference**. From it, the lifetime that the analysis takes as a reference is modified. The base case is 1, as it allows to see the results on the shortest time scale, but it is possible to place the reference as desired.
- **Discount rate**. Represents the increase in monetary value each year.

With these inputs it has a great variability to work, being able to analyze everything in a very specific way, obtaining some data that are commented on below.

6.3.2 Outputs

All the data entered will go through the financial model, obtaining several tables like this:

Increased lifetime	1				
YEARS	2013	2014	2015	2016	2017
# Launch	0	0	0	0	0
REVENUES	$ -	$ -	$ -	$ -	$ -
CAPEX COSTS	$ -	$ -	$ -	$ -	$ -
OPEX COSTS	$ -	$ -	$ -	$ -	$ -
COST	$ -	$ -	$ -	$ -	$ -
BALANCE	$ -	$ -	$ -	$ -	$ -
Accumulated balance	$ -	$ -	$ -	$ -	$ -
Discount Acc Bal	$ -	$ -	$ -	$ -	$ -

Figure 6.11: One Cubesat Feasibility study tab Outputs (1). DISCOVEX.

It can be observed the increase in lifetime with respect to the base input named before is the differentiated cell, performing the calculation process for every 10 different lifetimes (in this case, from 1 to 10 years).

From there, the data obtained resulting in the economic balance that would be had each year. The last two rows represent this accumulated balance over the years (until 2030 capability) and the same applying the discount ratio inserted in the table of inputs.

In addition, three tables appear that show these final values after 6, 11 and 17 years 6.12, being able to see the accumulated balance after this time, for each lifetime.
This will facilitate the graphic and visual representation, allowing greater ease of analysis.

Result 17 years			
Lifetime increase	Base case years	+1	+2
Final Accumulated balance	$ -	$ -	$ -
$ Investment	$ -	$ -	$ -
Results 11 years			
Lifetime increase	Base case years	+1	+2
Final Accumulated balance	$ -	$ -	$ -
$ Investment	$ -	$ -	$ -
Results 6 years			
Lifetime increase	Base case years	+1	+2
Final Accumulated balance	$ -	$ -	$ -
$ Investment	$ -	$ -	$ -

Figure 6.12: One Cubesat Feasibility study tab Outputs (2). DISCOVEX.

With this is possible to analyze the difference in each case with respect to the base case, which can be understood as the money available to invest in improving the satellite without having losses with respect to the base case.

A fraction of this money is the objective of this thesis, because materials are large participants in the life time of the objects that orbit VLEO.

The analysis of the results obtained with the tool will be analyzed in the next and last chapter.
But what is certain is that now, DISCOVEX is prepared to evaluate VLEO missions quite individually and concretely, with great ease of updating and adapting to time and user need to use it.
From now on, when more concrete the data it's provided to DISCOVEX, closer to reality its results will be.

Chapter 7

Results

In this chapter an analysis of the results that DISCOVEX can offer with its two new functions will be carried out.

To perform this analysis, different cases will be raised; one as close to reality as possible, with the information contrasted and collected explained in previous sections, another pessimistic and another optimistic.

7.1 Feasibility study results

7.1.1 Base case

In the initial case, values have been taken as close as possible to reality, through the different references and the necessary conservative estimates.
This values are present bellow.

Input data	First year
$/km^2	1
% Useful images	20%
% ISS	50%
% Secondary	50,00%
% Sold photos	1%
Degradation rate	-4%
Inflation rate	4%

Figure 7.1: Feasibility study tab inputs (Real case). DISCOVEX.

With these values, DISCOVEX performs the calculations to obtain the accumulated economic balance for the different lifetime and each year.
The representation of this evolution is now shown.

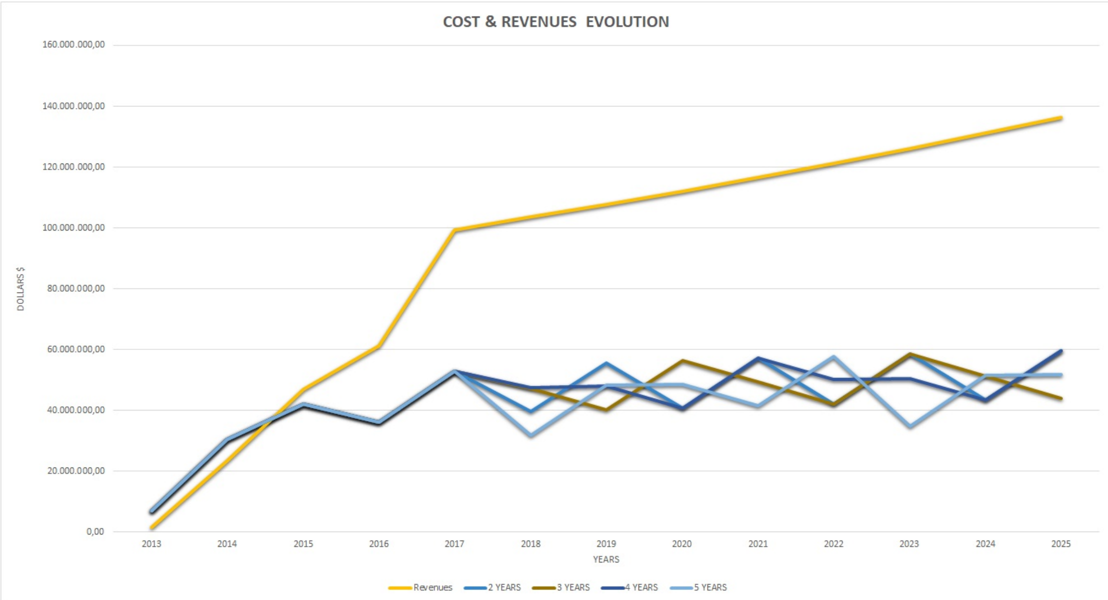

Figure 7.2: Cost Revenues evolution for different lifetimes. DISCOVEX.

Do not forget that this DISCOVEX function takes as a reference the Planet mission, so it could be considered a simulation, towards the future, of its constellation of 140 CubeSats.

This representation shows the total costs associated with the mission, whose peaks represent a higher launch number.

If represents the accumulated balance for the two dates mentioned above, as given by DISCOVEX (7.3), result:

Accumulated balance	Year	Lifetime
559.568.593	2025	1
622.229.139	2025	2
630.209.505	2025	3
621.669.670	2025	4
653.098.475	2025	5
672.864.412	2025	6
660.529.504	2025	7
648.523.468	2025	8
645.321.396	2025	9
617.963.590	2025	10

Accumulated balance	Year	Lifetime
559.568.593	2025	1
622.229.139	2025	2
630.209.505	2025	3
621.669.670	2025	4
653.098.475	2025	5
672.864.412	2025	6
660.529.504	2025	7
648.523.468	2025	8
645.321.396	2025	9
617.963.590	2025	10

Figure 7.3: Accumulated balance for two different dates. DISCOVEX.

Figure 7.4: Accumulate balance evolution for two different dates (2020 & 2025). DISCOVEX.

The most interesting thing to see is that, after a certain lifetime, the balance begins to decrease, which means that it would not be profitable to manufacture satellites with greater useful life.

This is a clear key factor to assess the extent to which it would be useful to invest in improving the satellite, which in this case would have a limit of 6 or 7 years of life.

Finally, it is possible to represent the NPV, IRR and Payback values to see how they evolote with lifetime.

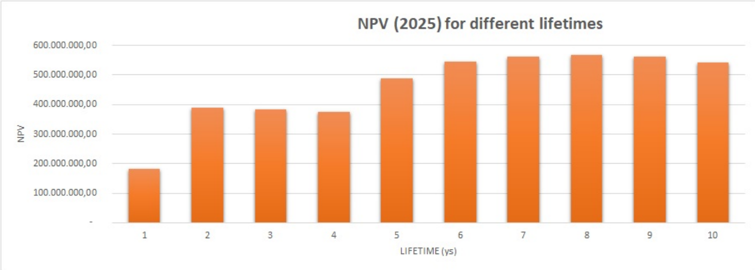

Figure 7.5: NPV evolution with lifetime. DISCOVEX.

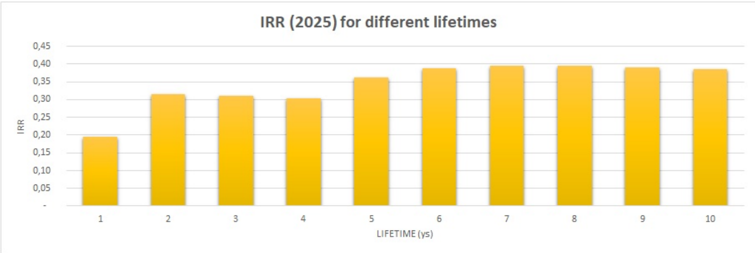

Figure 7.6: IRR evolution with lifetime. DISCOVEX.

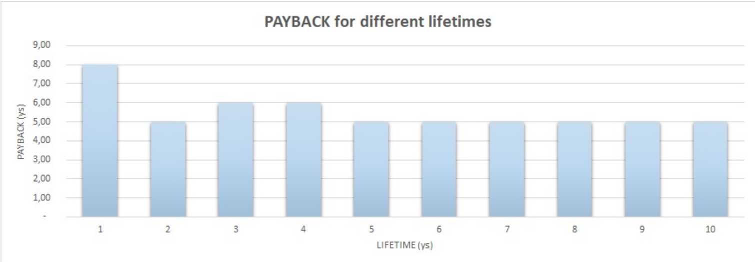

Figure 7.7: Payback evolution with lifetime. DISCOVEX.

Here it is possible to see that all are positive for the viability of the project, increasing with the lifetime.

It is observed again that, after 6 or 7 years of age, the mission payback is not affected. This may be because, for very high lifetime, the *feasibility study tab* cannot take into account sufficient years to evaluate it.
The number of years of analysis could be extended so that it can take into account higher life times.
In fact, in the section designed for a single cubesat it is possible, since it represents until the year 2030.

7.1.2 Pessimistic & Optimistic cases

The process is now carried out for two cases farther from the base case. For this, factors such as the percentage and price of images sold or the degradation ratio will vary positively and negatively.
This is intended to show the sensitive nature of the financial model with the variation of this factor.
Next, the Inputs of each case will be shown first, then the representation of the results.

Input data	First year
$/km^2	0,8
% Useful images	18%
% ISS	50%
% Secondary	50,00%
% Sold photos	1%
Degradation rate	-6%
Inflation rate	4%

[Pessimistic]

Input data	First year
$/km^2	1,2
% Useful images	20%
% ISS	50%
% Secondary	50,00%
% Sold photos	1%
Degradation rate	-3%
Inflation rate	4%

[Optimistic]

Figure 7.8: Pessimistic & Optimistic inputs. DISCOVEX.

Which offers the some like the follow results:

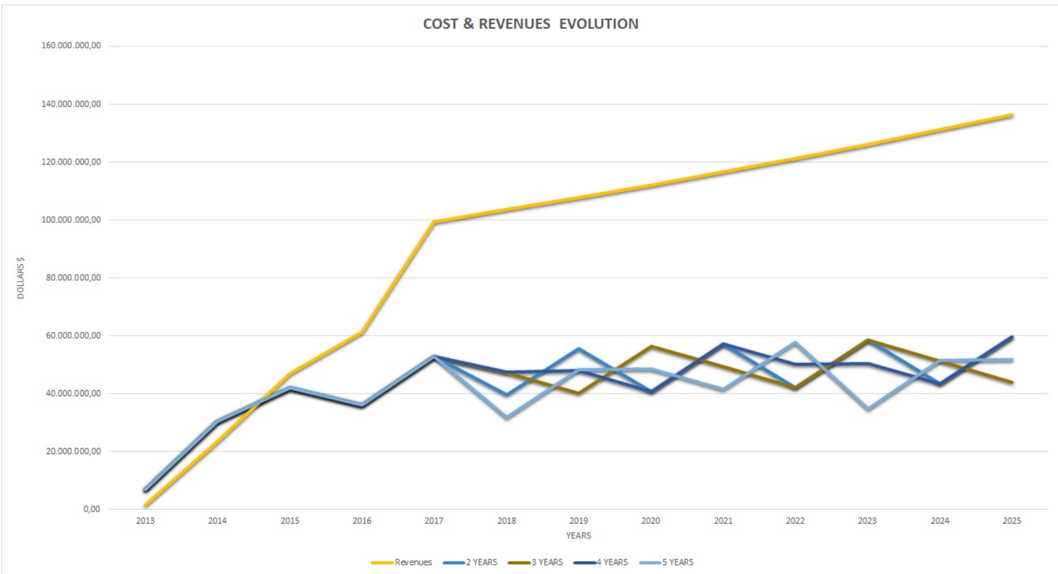

Figure 7.9: Cost Revenues evolution for different lifetimes.Pessimistic case. DISCOVEX.

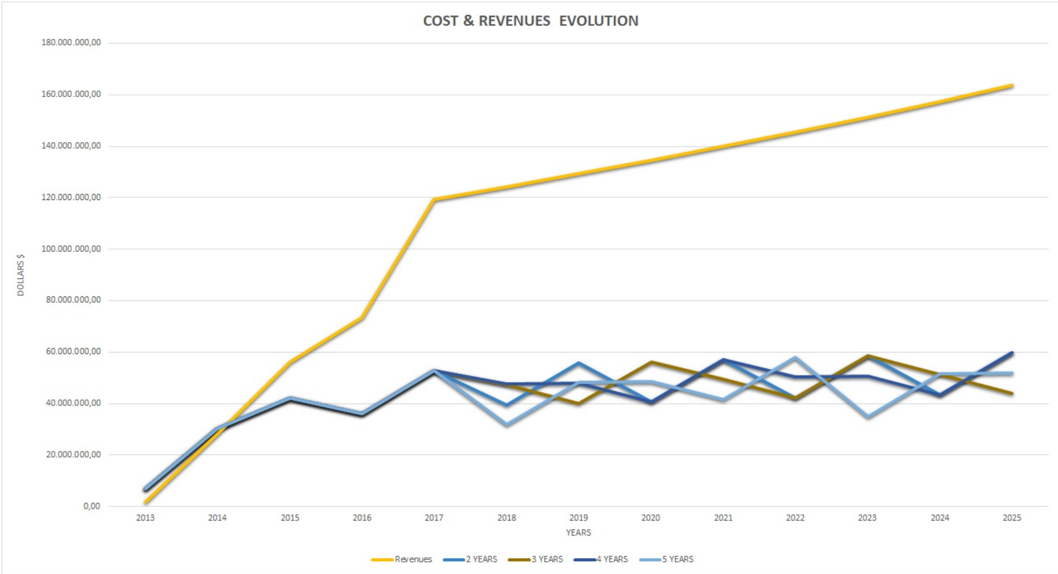

Figure 7.10: Cost Revenues evolution for different lifetimes. Optimistic case. DISCOVEX.

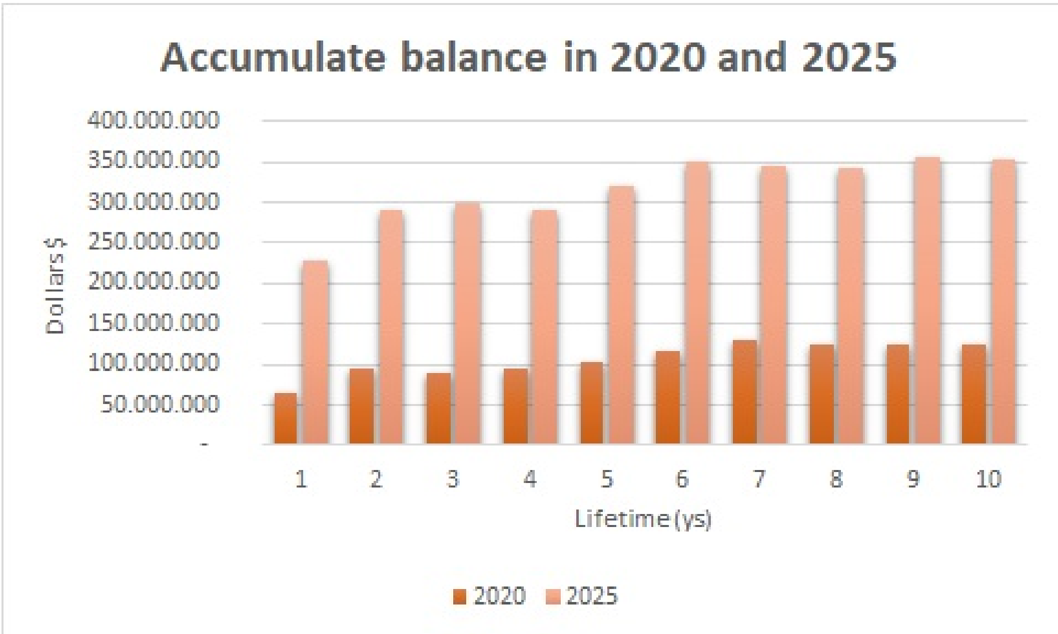

Figure 7.11: Accumulate balance for two different dates.Optimistic case. DISCOVEX

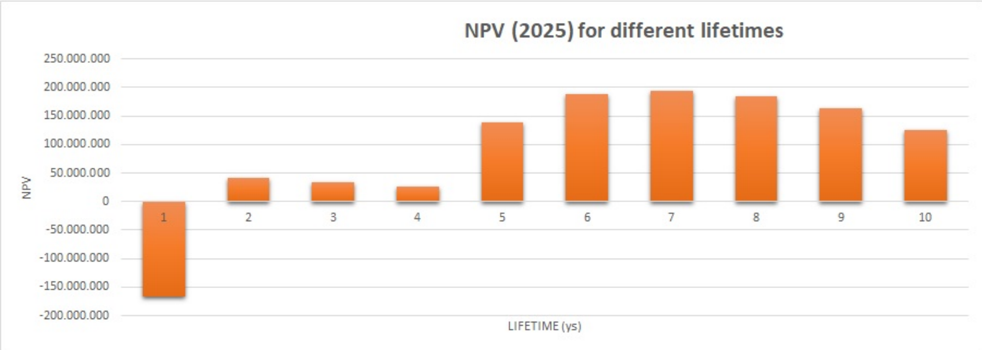

Figure 7.12: NPV evolution with lifetime.Pessimistic case. DISCOVEX.

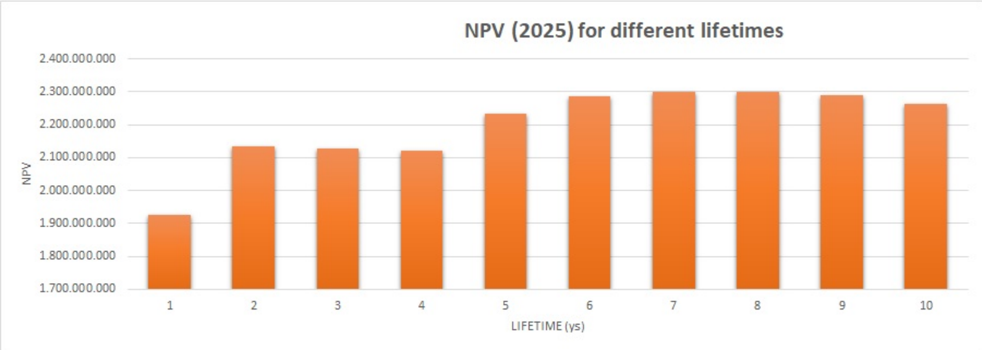

Figure 7.13: NPV evolution with lifetime. Optimistic case. DISCOVEX.

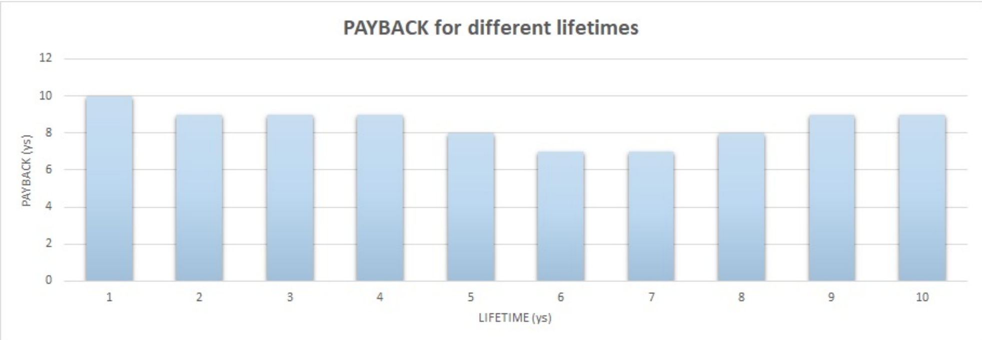

Figure 7.14: Payback evolution with lifetime. Pessimistic case. DISCOVEX.

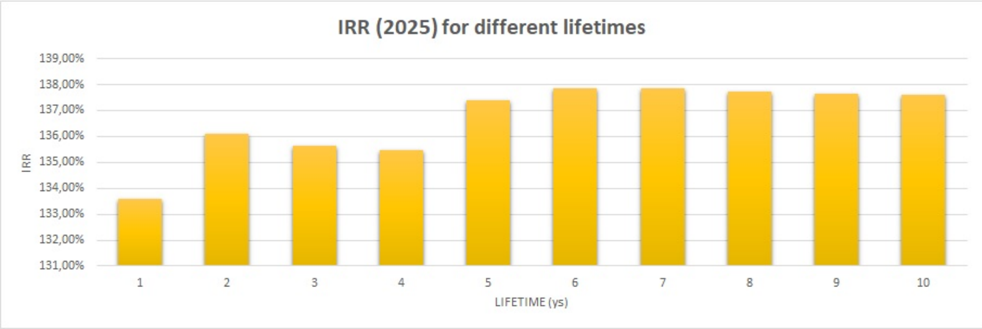

Figure 7.15: IRR evolution with lifetime. Optimistic case. DISCOVEX.

It is seen that, through Discovex, with the *Feasibility study tab*, the general balances of the defined mission can be represented, providing logical results with a good level of adjustment.
Making small variations in such a large constellation produces large changes in these balances, but still the viability of the mission is maintained.

It is important to point out the value of lifetime limit mentioned above, as it represents the maximum that satellites can be used, requiring an improvement, for example in materials, that reduces the degradation rate.

To deepen this aspect, the individual analysis function of DISCOVEX was created, where these values can be evaluated with greater adjustment.

7.2 One CubeSat feasibility study results

It will proceed in the same way as in the previous section. First, a base case will be represented, conservative, and then vary it to confirm the tool.
This will allow appreciate the usefulness of the tool and evaluate the results.

7.2.1 Base case

The same values used for the constellation feasibility case are indicated, but now, only one Cubesat will be taken into account 7.16.

# SATELLITES	1
KM2/DAY (1sat)	1.666.666,67
$/KM2	1
%USEFUL	20,00%
DEGRADATION RATE	-4,00%
%SOLD	1,00%
Inflation	4,00%
REVENUES/DAY	$ 3.333,33
Lifetime reference	1
Discount rate	4,00%

Figure 7.16: Inputs values. Base case. DISCOVEX.

The results obtained are those shown in the table in figure ??. They show the accumulated balance and the possible extra investment (obtained as the difference in which it has increased compared to the previous year) that can be used to improve the satellite.

YEARS	2013	2014	2015	2016	2017	2018	2019	2020	2021
# Launch	1	1	1	1	1	1	1	1	1
REVENUES	$ 1.216.666,67	$ 1.263.308,80	$ 1.314.000,00	$ 1.362.666,67	$ 1.411.333,33	$ 1.460.000,00	$ 1.508.666,67	$ 1.557.333,33	$ 1.606.000,00
CAPEX COSTS	$ 470.254,19	$ 470.254,19	$ 470.254,19	$ 470.254,19	$ 470.254,19	$ 470.254,19	$ 470.254,19	$ 470.254,19	$ 470.254,19
OPEX COSTS	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01
COST	$ 1.383.797,20	$ 1.383.797,20	$ 1.383.797,20	$ 1.383.797,20	$ 1.383.797,20	$ 1.383.797,20	$ 1.383.797,20	$ 1.383.797,20	$ 1.383.797,20
BALANCE	$ -167.130,53	$ -120.488,40	$ -69.797,20	$ -21.130,53	$ 27.536,13	$ 76.202,80	$ 124.869,47	$ 173.536,13	$ 222.202,80
Accumulated balance	$ -167.130,53	$ -287.618,93	$ -357.416,13	$ -378.546,66	$ -351.010,53	$ -274.807,73	**$ -149.938,26**	$ 23.597,87	$ 245.800,67
Discount Acc Bal	$ -167.130,53	$ -276.556,66	$ -330.451,30	$ -336.526,61	$ -300.045,27	$ -225.871,92	**$ -118.498,39**	$ 17.932,44	$ 179.604,15

Figure 7.17: Results table. Base case. DISCOVEX.

Figure 7.17 represents the initial case for 1 year lifetime. With this as a reference, the process is performed the same for 10 different possible lifetime increments of the satellite 7.18. All this evolution with years and lifetimes is represented in 7.19.

Increased lifetime	3								
YEARS	2013	2014	2015	2016	2017	2018	2019	2020	2021
# Launch	1	0	0	0	1	0	0	0	1
REVENUES	$ 1.216.666,67	$ 1.214.720,00	$ 1.208.880,00	$ 1.199.146,67	$ 1.411.333,33	$ 1.401.600,00	$ 1.387.973,33	$ 1.370.453,33	$ 1.606.000,00
CAPEX COSTS	$ 470.254,19	$ -	$ -	$ -	$ 470.254,19	$ -	$ -	$ -	$ 470.254,19
OPEX COSTS	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 913.543,01
COST	$ 1.383.797,20	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 1.383.797,20	$ 913.543,01	$ 913.543,01	$ 913.543,01	$ 1.383.797,20
BALANCE	$ -167.130,53	$ 301.176,99	$ 295.336,99	$ 285.603,66	$ 27.536,13	$ 488.056,99	$ 474.430,32	$ 456.910,32	$ 222.202,80
Accumulated balance	$ -167.130,53	$ 134.046,46	$ 429.383,45	$ 714.987,11	$ 742.523,24	$ 1.230.580,23	$ 1.705.010,56	$ 2.161.920,88	$ 2.384.123,68
Discount Acc Bal	$ -167.130,53	$ 128.890,83	$ 396.989,14	$ 635.620,94	$ 634.711,98	$ 1.011.447,25	$ 1.347.494,61	$ 1.642.882,19	$ 1.742.055,82

Figure 7.18: Results table. Base case. 3 years increase table. DISCOVEX.

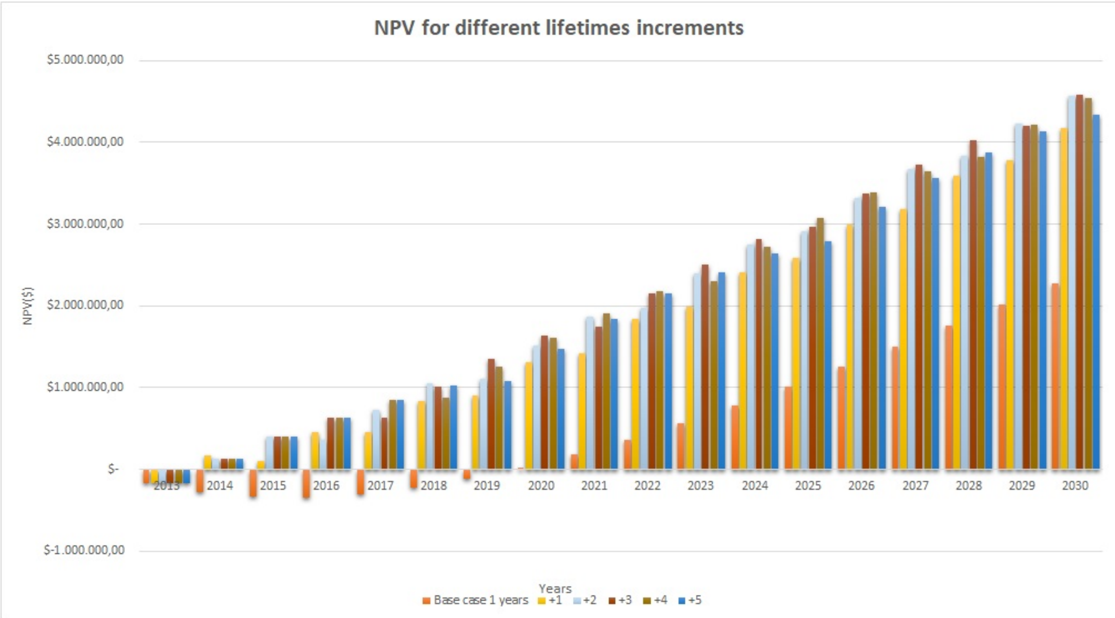

Figure 7.19: NPV or Accumulate balance for differents lifetime. Base case. DISCOVEX.

With the balances of each table, which are collected the information for every year until 2030, its possible to obtain the investment available each year to improve the satellite for the different lifetime increase.

For this, the results are taken in a concrete number of years of each lifetime increases.
The possible investment is obtained as the difference between the economic balance of the satellite for a given lifetime and the balance that the base case or reference would have. The case shown corresponds to the accumulated balance after 6 years.

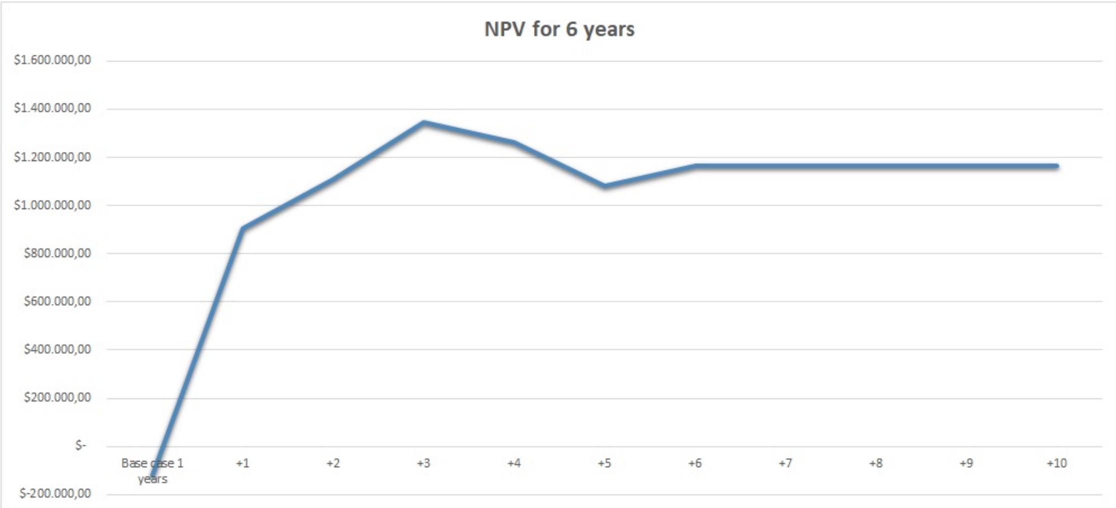

Figure 7.20: NPV or Accumulate balance in the sixth year for different lifetimes. Base case. DISCOVEX.

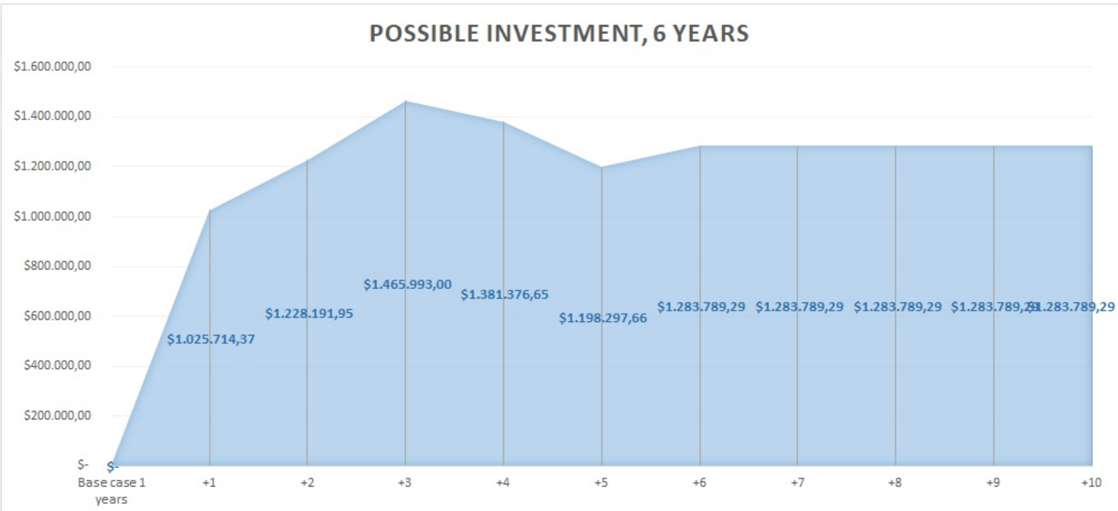

Figure 7.21: Possible investment in the sixth year and different lifetime. Base case. DISCOVEX.

What this *possible investment* represents is the amount of money available, under the financial model based on the mission of Planet, that it would take in six years to achieve the lifetime increase of a satellite (in the case, type Cubesat) and that is economically profitable compared to one who lives a single year.

This information can be a great interest when is necessary to improve some aspect of the satellite.
For example, if the material of which the satellite is composed is capable of surviving trhee or four years, with this tool it can be obtained almost immediately what could be invested after that time.
Thus, it is possible to determine how much is destined for each satellite improvement, from the number of year that each one appears needed.

The possible investment after eleven and seventeen years are available as standard on DISCOVEX.

This achieves a more objective view of the results than the *Feasibility study tab*, providing concrete information on how much money is available based on the increase in lifetime that is wanted to achieve.
The results are consistent with the information available on previous experiences, so, at this point, the tool provides clear and logical information, the tool work properly.

7.2.2 Variations from base case

Once it's understood the operation and scope of this DISCOVEX function, only have to vary the data depending on the need that is required.
For example, a little improve in the sale price of the image generates an significant increase in the possible investment with respect to the base case (7.22)

Figure 7.22: Possible investment in the sixth year and different lifetime. Image price: 1,4$/km2. DISCOVEX.

The sensitivity of the price of the photo is logical to work surfaces of thousands of kilometers per day. On the other hand, lowering them does not imply a negative investment margin and a profit margin continues.7.23

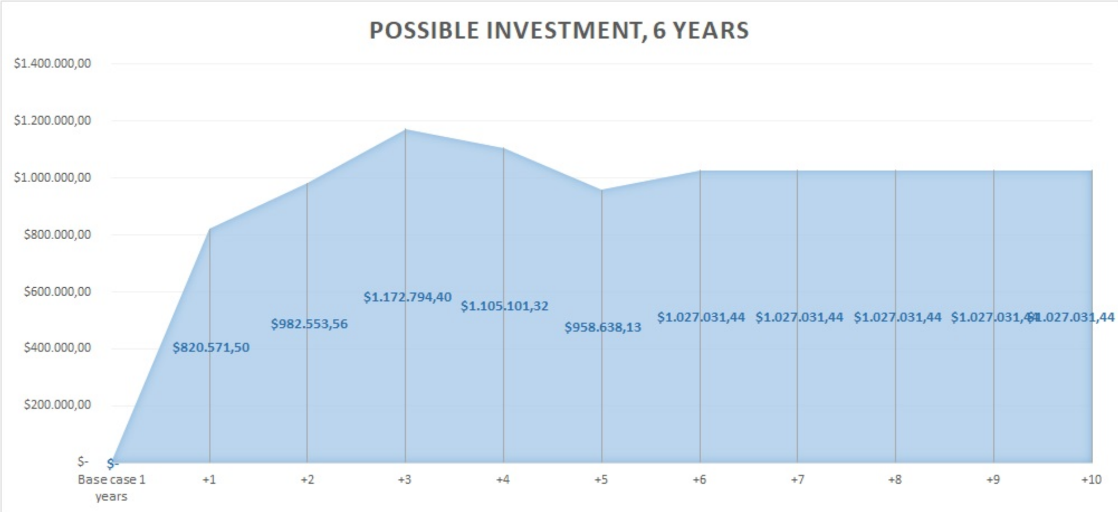

Figure 7.23: Possible investment in the sixth year and different lifetime. Image price: 0,8$/km2. DISCOVEX.

However, the most interesting factor could be the degradation ratio, since it limits the useful life of the satellite over the years.
Decreasing this factor translates into improvements of spacecraft, in its different systems and materials.

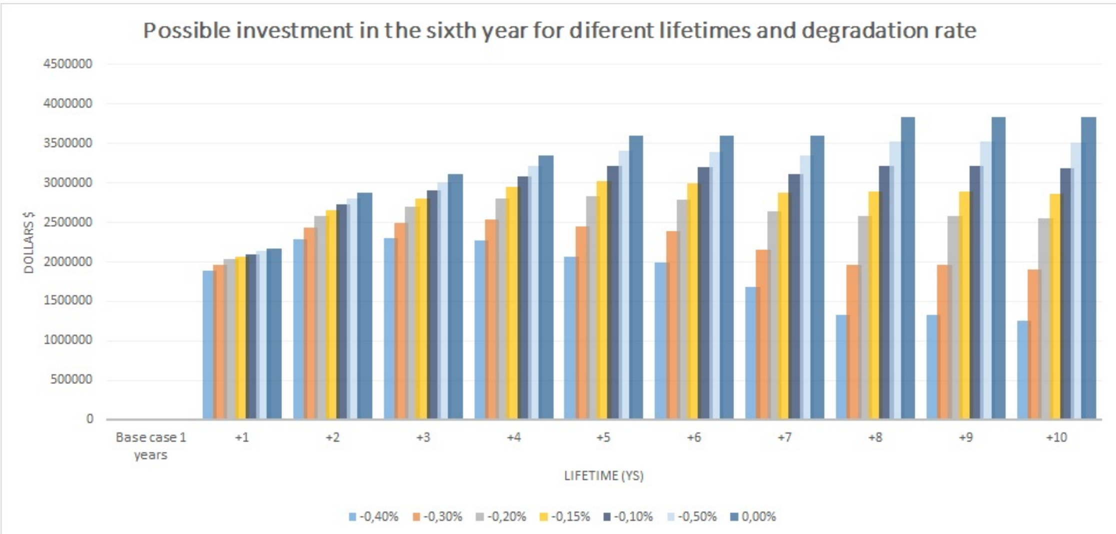

Figure 7.24: Possible investment in the sixth year for diferent lifetimes and degradation rate. DISCOVEX.

By varying it, it's clearly represent the decreasing of this factor through improvements in materials allows to generate higher revenues that translate into more possible investment to follow.
The important thing is that the results are logical and represents the delicacy that DISCOVEX now has. they represent very closely the values in which such a project would move.

In summary, the utility of these two new functions is demonstrated, following more the line of this thesis of the individual satellite section.
With it is possible to get very useful information about the budgets in which a determined mission would move.

It is also true that the DISCOVEX tool can perform much more varied and specific analyzes, but the best thing about it is that it is designed that adding or modifying things is very simple.

An adaptation to more types of satellites, or a specific function that breaks down the aspects related to the materials could be very useful in the future.

The design by years of DISCOVEX also allows working with deadlines for the evaluation of the different elements that make the satellite, which usually have different useful lives.
From knowing how much the material is able to remain stable in these orbits, a detailed analysis of the economic factors surrounding its improvement can be made.
And so with all systems with the possibility of improvement.

It is definitely a great point of tuning the tool, offering results wich demonstrate the possible economic viability of investing, for example, in new materials, that was the ultimate end of this thesis.

Chapter 8

Environmental impact

The human impact on the nature of planet Earth has gone from being a reason for discussion to a completely appreciable reality day by day in almost any corner of the world. Sustainability The Earth requires a very special treatment by humans from now on.

While awareness of this is growing in society, the inclusion of renewable energy, cleaner and more efficient systems and control and management of waste must be exponential.

The development of fuel-free propulsive systems such as ABEP, which is presented as a hopeful alternative for space-free propulsion without emissions, would be a breakthrough in terms of reducing space debris.
Clearly, the development of new materials also implies greater efficiency of satellites, reducing their number and giving them more lifetime.
This would collaborate a lot in the development of more eco-space missions, which represents a small portion of all the influential factors in the atmosphere's deterioration available to humans.

In addition, the tool discussed in this document could be adapted to take into account an environmental factor that limits the results within an *environmental feasibility*.

Chapter 9

Conclusion

9.1 General conclusion of the thesis

With the develop of this thesis, an exhaustive analysis of the feasibility of the missions in VLEO has been carried out. It allows to have a global vision of the budgets that flow, offering data related with the possible investment that there would be for satellite improvements. It has been possible to improve a great tool like DISCOVEX, allowing to obtain much tighter results.

Most of the work done on this project has been to develop DISCOVEX, providing it with a better result's analysis and representation.
With this is possible to effectively evaluate the information obtained.

On the other hand, the results are clarifying the logic behind the business of Earth's observation and give consistent values.
Although in this thesis the evaluation of results does not deepen too much, being able to make numerous variations to analyze, it is concluded that this analysis should be carried out taking into account other factors that need some of these possible investments, which will depend, in turn, on the materials that compose them.

For this the reading of the thesis of my partner Alvaro Juzgado Perez [24] is recommended. In it, more variations are made in the specifications of the mission, giving a much more varied view of the results and seeing how, for example, it affects the inclusion of a new expense, which can be considered destined to some aspect.
He also takes into account the ABEP propulsion system, on which his thesis is based.

In general it has been possible to recognize the amount of money that can be allocated to the improvement in materials, but it is immersed in the total that could be allocated for all systems to improve.
That is why the tool has been maintained with the format of adaptability that it had, because from here, the specification of what portion of money could be allocated to each subsystem of the satellite would allow DISCOVEX to give us values very close to the reality about it .

It is obvious that the development of new materials such as graphene advances rapidly, but knowing the economic values that it moves is still not very accurate.
That is why having a tool that allows to analyze the feasibility of the missions with the necessary estimates is a great step.
To specify about the lifetime that ABEP system improves, about the price of materials and their implementation or about image capture systems is to give DISCOVEX enough *foos* to work and offer clear results, allowing to know from what year, how much and with what security can be invested to achieve benefits by providing the satellite (in the case, a CubeSat) with a lifetime determined.

What is certain is that the implementation of this type of orbit is increasing and the opportunities it offers are known. Now it is not only a feeling, now DISCOVEX is who offers encouraging results and allows to believe that there is positive economic feasibility to confront necessary or desired improvements.

9.2 Future steps

From this work, different tasks are proposed that can be carried out in the future. Some of them are necessary to achieve the objectives of the *Discoverer* project, and others are complementary to the existing works:

- Analysis of the distribution of the investment for the different systems. Being able to assign one to each aspect of the satellite.

- Simulation of the results offered by DISCOVEX for many specific specifications.

  of the DISCOVEX tool to offer missions with different types of satellite and different types of payloads.

  study of the DISCOVEX tool and its potential value.

and anyone who can generate the connoisseur of this thesis.

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